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THE EDUCATION OF ATTENTION IN AIMING AT A FAR TARGET: TRAINING VISUAL CONTROL IN BASKETBALL JUMP SHOOTING

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ABSTRACT

We examined the effects of perceptual training on basketball jump shooting using a combination of single-subject and group design. Six participants received eight weeks of visual control training in which they only had vision during the final ~350 ms before ball release (the final period). Taking an ecological approach to perceptual learning, we expected that this would force participants to pick up relevant information until ball release, allowing for the use of the latest possible update of the relative target position. The training consisted of shooting from behind a screen and shooting while wearing liquid-crystal goggles. Participants increased their final period duration. In addition, they increased their field goal and three-point percentages in games, in contrast to four control participants from the same team. It is concluded that visual control training can change the temporal pattern of shooting and improve performance by enhancing the timing of information detection.

Key Words: perceptual skill, ecological psychology, visual information

In general, most practice in sports is directed at physical conditioning and improving technical skills and game tactics. The training of perceptual skill is rarely addressed (Abernethy, 1996). Yet, in the sport science literature there are more and more indications that perceptual expertise is an important characteristic of expertise in many sports (for overviews, see Abernethy, Wann, & Parks, 1998; Williams & Grant, 1999; Williams & Ward, 2003). A key question is whether it is possible to speed up or optimize the development of perceptual skills through training. This approach would provide a valuable addition to sports practice. However, perceptual training studies, especially involving on-court test situations, are still rare (Williams & Ward, 2003). In the current study, we investigated the effect of an on-court visual control training program on basketball jump shooting performance.

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PERCEPTUAL SKILL IN SPORT

Perceptual expertise is not due to individuals' superior general visual characteristics (visual hardware), such as static and dynamic acuity, depth perception, color vision, and peripheral visual field, but rather their superior "visual software" which is concerned with more sport-specific abilities, such as the recognition and interpretation of visual information (e.g., Abernethy et al., 1998; Williams & Grant, 1999). Whereas in the sport science literature perceptual expertise is usually taken as mainly following from an "enhanced cognitive knowledge base" (see Williams, Davids, & Williams, 1999), we will take an ecological approach to the development of perceptual expertise, with an emphasis on improved information detection.

In the ecological approach to perception, perceptual learning entails two processes: the education of attention (Gibson, 1966; Jacobs & Michaels, 2002; Michaels & Carello, 1981) and calibration of action (Jacobs & Michaels, 2002; Withagen & Michaels, 2002). The education of attention is described as a process of selection or differentiation, where the perceiver is "narrowing down from a vast manifold of information to the minimal, optimal information that specifies the affordance of an event, object or layout" (Gibson & Pick, 2001, pp. 150-151). Jacobs and Michaels argued that education of attention entails a change from detecting non-specifying (less useful) to specifying (more useful) variables. In short, the education of attention is seen as the process by which one learns which variables to attend to in which situation, that is, the process by which one learns to control the detection of information (see also Van der Kamp, Oudejans, & Savelsbergh, 2003).

The calibration of action is a process of tuning that scales movements to the environment (Jacobs & Michaels, 2002; Withagen & Michaels, 2002). It is directed at establishing and maintaining a specific relation between information guiding a movement and the unfolding movement itself (Van der Kamp et al., 2003; Withagen & Michaels, 2002). Being able to detect a specifying or at least a useful variable (i.e., when attention has been educated to pick up this variable) does not automatically mean that one can also optimally guide one's actions on the basis of this information. A learning process is needed in which the relation between the variable and successful action is established. In practice, the processes of education of attention and calibration of action can, and probably will, overlap in time. It follows that any change in the use of a variable is necessarily accompanied or followed by the calibration of the action to this new variable. As an example, when a basketball player educates his or her attention to the use of a certain variable that specifies, for example, the distance to the rim, then the player also needs to establish the relation between this variable and forces needed to project the ball appropriately over the perceived distance.

PERCEPTUAL SKILL IN AIMING AT A FAR TARGET

In far-aiming tasks, such as rifle shooting, basketball free-throw shooting, and billiards, an important characteristic of perceptual skill is the duration of the final fixation on the

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VISUAL CONTROL IN BASKETBALL JUMP SHOOTING

In the current study, we investigated the effects of visual control training on basketball jump-shooting performance using expert male players. In contrast to most other far-aiming tasks where gaze behavior has been investigated (e.g., rifle shooting, basketball free-throw shooting, billiards), in basketball jump-shooting aiming is not from a (relatively) stationary position but from a moving point of observation. Basketball jump shooting is a very dynamic task involving whole body movements and time pressure. The time pressure follows from the speed of a basketball game as well as from the simple fact that the jump provides only limited time to make the shot. If the ball is not released before landing, a travel violation is made.

Oudejans, van de Langenberg, and Hutter (2002) tested the visual control of expert male basketball players taking jump shots. For the relatively long-distance jump shots they distinguished two major shooting styles.¹ With the high style or overhead-backspin style (e.g., Hay, 1993; term from Hamilton & Reinschmidt, 1997) the ball is lifted up above the head and subsequently projected with a quick and forceful extension of the dominant elbow and a flexion of the wrist (Hay, 1993). The advantages of this shooting style are that it allows backspin and a relative high point of release, both of which appear to be critical variables in shooting performance (Hamilton & Reinschmidt, 1997; Hudson, 1985). Moreover, with this high style the shooter can, in principle, look at the basket from underneath the ball when it is held in the shooting position (Oudejans et al., 2002). The low style (e.g., Kreighbaum & Barthels, 1981; Miller & Bartlett, 1996) is a pushing style during which the ball and hands remain below or at eye level for almost the entire shooting action. During the final extension, ball and hands are largely in front of the face and, hence, in the field of view.

A difference between the two styles that is relevant for the visual control of the aiming movements is whether the shooter can, in principle, look at the basket from underneath the ball during the final shooting movements until ball release (high style) or not (low style; Oudejans et al., 2002). In line with the possibility for late viewing with the high shooting style, Oudejans et al. demonstrated that with this style late vision provided necessary and sufficient information for expert shooters to visually control their shooting. Looking late seems to be essential for high-style expert shooting. It might be the case that near-experts do not yet exhibit an optimal timing and duration of information pickup, that is, they pick up relevant information either too early (before the final period), too brief, or both. Research with basketball free throws and volleyball serve receptions has shown that near-experts may exhibit sub-optimal gaze behavior during the execution of the task (Vickers, 1996; Vickers & Adolphe, 1997). The question now is whether the timing and duration of the information pickup can be improved with specially designed perceptual training.

¹Shooting style in this context refers to the movements that are made with the hands and the ball. It does not refer to what the feet do as these could remain set on the floor, as in the set shot or free throw, or jump up as in a jump shot. Hay (1993) indicates that the arm techniques used in the set shot and the jump shot are essentially the same.

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target prior to initiating the final movements (e.g., Janelle, Hillman, Apparies, & Murray, 2000; Vickers, 1996; Williams, Singer, & Frehlich, 2002). This final fixation is called quiet eye (QE) and it appears that experts fixate their gaze at the target for a (relatively) long time before initiating the final movements. A longer QE duration appears to be a characteristic of higher levels of skill and accuracy in sport. Recently, Vickers, Rodrigues, and Edworthy (2000) showed that the accuracy of dart throwing was affected by the temporal offset of QE relative to the phase of the arm movement demonstrating the importance of the timing of QE. Fixating the target too soon or too late did not lead to the same level of accuracy as when looking was optimal, that is, just prior to the final movement being initiated (Vickers et al., 2000).

The longer QE period that is found in expert far aiming is usually interpreted as a reflection of "a critical period of cognitive processing during which the parameters of the movement such as force, direction, and velocity are fine-tuned and programmed" (Williams et al., 2002, p. 205). Although results regarding several tasks (e.g., basketball free-throw shooting, Vickers, 1996, and volleyball serve reception, Vickers & Adolphe, 1997) support this idea, it is by no means certain that QE duration is indeed reflective of underlying cognitive processing (Williams et al., 2002).

From an ecological perspective, we propose an explanation that originates in the idea that information is not static but evolves over time (Gibson, 1979; 1986; Michaels & Carello, 1981). Only over time can there be information of persistence and change in the environment (Gibson, 1979; 1986), implying that information pickup always takes some time. In far aiming, proper information detection is a process that also takes time prior to and/or during the execution of the task. Perceiving the target relative to one's (changing) point of observation for some time (i.e., perceiving distance to the target and its rate of change) may provide a sound basis for controlling the aiming movements. In this line of argument an extension of the QE duration reflects a longer detection of information, which may be more useful for controlling the action (e.g., Fitch & Turvey, 1978), as it leads to a better perception of the relation between the target and the point of observation. As for the timing of QE, it seems relevant to pickup information when it is most useful for optimally guiding the aiming movements.

An important question is whether and how it is possible to speed up the processes of education of attention and calibration of action in sport. Most research on perceptual training in sport has been done under laboratory conditions using film-based tests (for a review, see Williams & Grant, 1999). Of the ten perceptual training studies discussed by Williams and Grant, only two employed on-court interventions. Vickers and Adolphe (1997) determined what optimal expert gaze behavior was (onset and offset of QE) in receiving volleyball serves in order to produce a good forearm pass. As a follow up, Adolphe, Vickers, and Laplante (1997) trained expert volleyball players who exhibited non-optimal gaze behavior. Both gaze behavior and serve reception improved, indicating that perceptual training can be effective, even with expert athletes. More recently, Harle and Vickers (2001) succeeded in extending the QE duration and improving the free-throw percentages in female collegiate basketball players, using a specific QE training program.

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We investigated the effects of an eight-week visual control training program on the basketball jump-shooting performance of expert, young male (16-19 years) basketball players shooting with a high style. The training aimed to improve the information pickup during the final period, just before ball release. This training procedure was achieved by providing vision only during the final period of a shot while wearing liquid crystal goggles as well as by having participants shoot from behind a screen. These procedures imposed constraints on vision that made visual information for shooting available only after ball and hands had passed the line of sight. Under the assumption that sub-optimal performance would normally entail information detection that would be either too early (before the final period) or too brief during the final period, it was expected that by excluding all vision prior to the final period, players' attention would be educated to the use of information available in this period. Since this information is necessary and sufficient for good performance in jump shooting with a high style, as was demonstrated by Oudejans et al. (2002), players were expected to converge on more useful information. We expected that possible improvements in information detection would become manifest via an extension of the final period, suggesting a longer period of information detection, as well as through better shooting as more useful information is used.

We used a single-subject design in combination with a group design. Single-subject designs encompass repeated measurement of the main dependent variable throughout the duration of the study (Hryciako & Martin, 1996). Several researchers argue that because in single-subject designs the "individual's behavior is observed for a period of time prior to the implementation of one or more experimental conditions" they "eliminate the need for a no-treatment control group" (Swain & Jones, p. 53; see also Bryon, 1987; Smith, 1988). By monitoring performance over a period of time both during baseline and intervention, chances are reduced that changes in performance during or after the intervention are caused by a factor other than the intervention.

There is much debate in the literature about the usefulness of single-subject designs in psychology, with the pros and cons being highlighted alternately (e.g., Furedy, 1999; Lejuez, Zvolensky, & Eifert, 1999; Reboussin & Morgan, 1996). Therefore, some authors advise to use single-subject designs in conjunction with the more common group designs (Lejuez et al., 1999; Wollman, 1986). This latter approach was adopted in the current study. As a cross check and to exclude external factors (such as, seasonal fluctuations in performance of the entire team) that might have played a role in the single-subject results, we also used a group design, albeit with a small number of participants.

METHOD

OVERVIEW OF THE STUDY

The study as a whole spanned three periods: pre-intervention, intervention, and post-intervention. The pre-intervention period consisted of the first five months of the nine-month competitive season. The intervention consisted of an eight-week visual control training program containing two different exercises: laboratory training executed at the university

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and screen training executed once or twice a week during regular team practices. The post-intervention period consisted of the last two months of the season.

PARTICIPANTS

We tested young, fairly high-level, players because they already have a well-developed jump shot technique for which it seems unlikely that possible performance increases are due to improvements in this technique itself. Six players from a team playing at the highest level for men under 21 in the Netherlands (National Youth League) volunteered to participate. The average age of the participants in this experimental group (EG) was 17 years (range 16-18) and they had on average seven years of basketball experience (range 4-11). The participants provided written informed consent.

Four other players from the team who did not join the intervention were used as a control group (CG), but only with respect to their game shooting percentages. The CG participants were matched to the EG participants with respect to their basketball quality and playing position on the basis of ratings by the coach. As to the number of shots taken in games, two participants of the CG (A and B) took sufficient shots for further analysis both within the single-subject and the group design. The other two participants (C and D) took sufficient shots to be included in the group analysis but not in the single-subject analyses. The CG did not enter any of the intervention or measurement sessions, but allowed us to use their game shooting percentages by providing written informed consent. They did not do the same structured shooting drill during practice as the EG (see below), but they did additional drills (mostly shooting) with special attention from the coach. As the CG followed the normal training routine of the team, a fair comparison could be made between the CG and the EG with respect to their shooting percentages in games. The average age of the CG was 17.5 years (range 15-19) and on average they had seven years of basketball experience (range 4-9).

EXPERIMENTAL SETUP

Laboratory training. In a large laboratory (7.5 m high) a basket was placed with a standard-size multiplex backboard (1.80 x 1.05 m; white backboard with black lines) and regulation rim (diameter 0.45 m, height 3.05 m). The ball used was a leather, official NBA regulation size ball. To manipulate vision the participant wore Plato liquid crystal (LC) goggles (Translucent Technologies, Toronto, Canada) that could be shut and opened with good (1-3 ms) temporal precision. The shooting movements of the shooter himself were used on-line to control shutting and opening of the goggles, using a procedure reported by Oudejans et al. (2002). Movement registration of hand and head were fed back to a computer that used the information to open the goggles when hand and ball were moved passed the line of sight. The article by Oudejans and Coolen (2003) is specifically devoted to a description of this procedure that we, for the sake of space, will not repeat here. Movements were registered at 100 Hz with Optotrak 3020 (Northern Digital Inc., Waterloo, Canada). All shots were videotaped from the side with a mini digital video Handycam camcorder (Sony, New York, USA). The video recordings

were synchronized with Optotrak via two red Light Emitting Diodes (LED), one indicating when a trial started and ended and the other when the marker on the hand passed the line of sight.

Screen training. The screen training was performed in the practice gym employed by the team. The same basket was used each time for the training. A sailcloth (4.5 m wide and 2.3 m high) tightened between two posts provided a screen so that shooters could shoot from behind it. Once set up at the free throw line, the screen had a height of 2.1 m.

PROCEDURES

Laboratory training. The laboratory training consisted of four sessions spread over the eight-week period. At the beginning of each session the participant was given time to warm up, after which the goggles were put on and the Optotrak markers were placed. The participant then took several training shots with full vision to get used to the equipment. Each session consisted of two viewing conditions: full vision and late vision, that is, vision during the final period only. The experiment started with 12 full-vision shots (goggles remained open) starting from the right followed by 13 full-vision shots starting from the left. Next the goggles were initially shut and then opened at the moment hand and ball passed the line of sight (late vision). The participant took a total of 100 shots in this condition (again after some practice trials). He started from the right side and after each 25 shots switched sides. After every 25 shots, there was a short break. The last condition was again full vision. The participant first took 12 shots starting from the left and finished with 13 shots starting from the right. Thus, in total 150 test shots were taken: 25 full-vision shots followed by 100 late-vision shots, followed by another 25 full-vision shots.

At the first visit the participant was given detailed instructions about how to execute the task. The initial position of the participant was at a perpendicular distance of 6-7 m from the basket about 1-2 m to the right or left of it (see Figure 1). The participant always shot from the middle position of a 1 m x 1 m square marked on the floor with white tape at about 5 m from the basket, just a little more than the standard free-throw distance. His task was to make one dribble, land on the shooting spot, jump up and take a jump shot. The participant was told at which side to start and when to switch sides. Each time one of the experimenters indicated when the participant could start, which was also the moment that the Optotrak registration began. The participant executed the task and when his hands passed the line of sight one of the LEDs switched on. Four seconds after initiation the registration ended. Hits were registered via a computer. One experimenter rebounded the ball and returned it to the participant.

At the end of the last laboratory session the screen as used during training was set up. Five additional shots were taken from behind the screen in order to determine the final period duration during shooting from behind the screen.

Screen training. Over the eight-week period 11 screen training sessions were organized. Depending on practice attendance participants received the screen training 6-10 times.

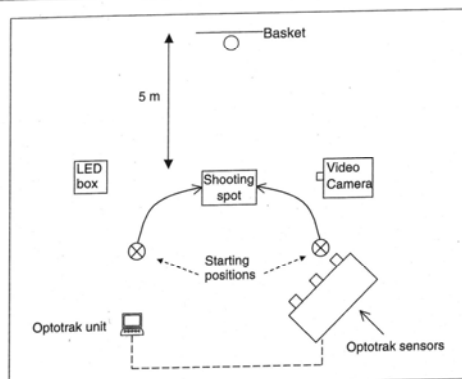


Figure 1. Plan view of laboratory setup.

The screen training was done with the six participants at the same time. Two people were rebounding and giving outlet passes. Two participants received the outlet passes and each passed the ball to one of the two shooters. The shooters shot from the spot behind the screen where they could barely see the top of the small rectangle on the backboard. When a shooter approached for the jump shot, the screen blocked their view of the basket. During the final instances of the jump shot, just before ball release (when they were in the air), the screen no longer occluded vision to the rim. Before the first screen training the participants were given some practice trials to locate the right spot to shoot from. The two shooters shot in turns. One started from the left and the other from the right. After both shooters had taken 25 shots, all six participants rotated and two other participants started shooting. The rotation stopped when each participant had taken 25 shots from each side, 50 in total. As mentioned, when the EG did the screen training, the participants of the CG were given additional attention by the coach under whose supervision they did additional practice or shooting drills.

DEPENDENT VARIABLES

Scoring results were kept for the first and last 25 shots of each laboratory training session (i.e., the full-vision shots). In addition, shooting percentages from real competition games played during the season were included. From the laboratory sessions, the sample number in the Optotrak output during which hand and ball passed the line of

sight was registered with an accuracy of 10 ms in both the full-vision and the late-vision conditions. By combining this moment with the moment of ball release (determined from video; accuracy 20 ms) the final period duration could be calculated.

RESULTS AND DISCUSSION

Not all participants in the EG were able to complete the experiment. For some participants, the experimental data were incomplete due to injuries, time constraints, or technical failure. The analyses reported below are based on 3, 4, or 5 participants. Sample sizes smaller than five normally require non-parametric statistical analyses (Siegel, 1956). We executed parametric as well as non-parametric test for all group analyses. As both kinds of analysis yielded the same results and conclusions, we only report the parametric tests. Effect sizes, indicating how many standard deviations the means under consideration differed, were calculated by taking the ratio of the difference between the two means and the standard deviation of the first mean (Cohen, 1988).

DURATION OF THE FINAL PERIOD

We computed the final period durations (in ms) for the following five situations: 1) the first 25 full-vision (FV) shots in the first laboratory training session (FV 1st 25 LAB1); 2) the first 25 full-vision shots in the last laboratory training session (FV 1st 25 LAB4); 3) the last 25 full-vision shots in the last laboratory training session (FV last 25 LAB4); 4) during

Table 1: The average duration of the final period (in ms) of the first 25 full-vision shots in the first laboratory training session (FV 1st 25 LAB1), the first 25 full-vision shots in the last laboratory training session (FV 1st 25 LAB4), the last 25 full-vision shots in the last laboratory training session (FV last 25 LAB4), during shooting from behind a screen (LV Screen), and with late vision wearing the goggles (LV Goggles). Standard deviations in parentheses.

Participant	FV 1st 25 LAB1	FV 1st 25 LAB4	FV last 25 LAB4	LV Screen	LV Goggles
1	265 (11.9)	299 (24.0)	287 (28.5)	302 (27.8)	306 (26.4)
2	420 (15.2)	426 (12.5)	436 (14.1)	454 (16.7)	448 (11.0)
4	346 (19.1)	353 (12.4)	351 (13.1)	356 (20.1)	344 (18.9)
5	352 (15.1)	385 (15.0)	390 (12.1)	390 (7.1)	408 (11.0)
6	381 (16.9)	400 (14.5)	413 (16.7)	416 (8.0)	424 (16.9)
Mean (SD)	353 (17.3)	373 (19.0)	373 (18.1)	384 (18.4)	386 (19.2)

FV = Full Vision

LV = Late Vision

LAB1 = first laboratory training session

LAB4 = last laboratory training session

late-vision [LV] shooting from behind a screen [LV Screen; taken from the additional five shots taken during the last lab session]; and 5) with late vision wearing the goggles [LV Goggles; taken from the last five late-vision shots of the last lab session]. The final period durations taken in these five different conditions are presented in Table 1.

The final period duration increases from full-vision shooting pre-intervention (Column 1), to full-vision shooting post-intervention (Column 2; long-term effect), and to full-vision post-goggle-training (Column 3). It further increases during late-vision shooting from behind the screen (Column 4) and with the goggles (Column 5). A within-participants (Condition: FV 1st 25 LAB1, FV 1st 25 LAB4, FV last 25 LAB4, LV Screen, LV Goggles) ANOVA on the final period durations showed a significant effect for Condition, $F(4, 16) = 9.98, p < .001, ES = 0.55$. Pair-wise comparisons were executed using the Bonferroni correction procedure [taking the correlation between conditions (.98) into account; see <http://home.clara.net/sisa/bonhlp.htm>]. This led to an adjustment of alpha to .048. The pair-wise comparisons revealed significant differences between most conditions as can be seen in Table 2 with small-to-moderate effect sizes (Cohen, 1988), or moderate-to-large, if one considers that we tested elite youth performers (Hopkins, Hawley, & Burke, 1997). It seems that participants extended their final periods under the influence of the visual control training.

Table 2: T-values and effect sizes (in parentheses) of the pair-wise comparisons among the five conditions: the first 25 full-vision shots in the first laboratory training session (FV 1st 25 LAB1), the first 25 full-vision shots in the last laboratory training session (FV 1st 25 LAB4), the last 25 full-vision shots in the last laboratory training session (FV last 25 LAB4), during shooting from behind a screen (LV Screen) and with late vision wearing the goggles (LV Goggles).

	FV 1st 25 LAB1	FV 1st 25 LAB4	FV last 25 LAB4	LV Screen
FV 1st 25 LAB1				
FV 1st 25 LAB4	3.32* (0.35)			
FV last 25 LAB4	4.31* (0.36)	0.09		
LV Screen	5.79* (0.55)	2.17* (0.23)	3.52* (0.19)	
LV Goggles	3.34* (0.58)	2.05* (0.28)	2.25* (0.23)	0.40

* $p < .05$; * $p < .01$; * $p = .054$, marginally significant

FV = Full Vision

LV = Late Vision

LAB1 = first laboratory training session

LAB4 = last laboratory training session

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FIELD GOALS

Experimental Group (Figure 2). For Participants 2, 3, and 4 mean performance increased from 29.3%, 39.1%, and 53.6% in the baseline phase to 43.5%, 58.1%, and 72.3% in the (post) intervention phase, respectively. These are increases of 48.5%, 48.7%, and 34.9% across phases. There were also increases in level of performance, from the final level of the baseline to the initial level of the post-baseline period (the numbers can be seen in Figure 2). The changes in level were 136%, 31.5%, and 74.5% for Participants 2, 3, and 4 respectively. The Binomial tests on the shooting performance of these three par-

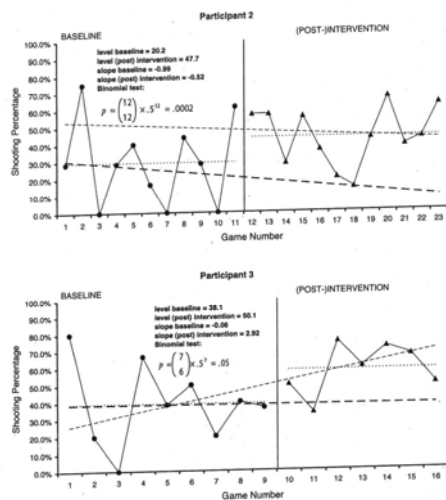


Figure 2. Field goal results for Participants 2-5 of the EG using the Split-middle analysis. Dotted lines show average performance levels. Striped lines represent the trends in performance (bold = baseline; thin = post-intervention). The vertical solid line indicates the transition from baseline to post-intervention.

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SHOOTING BEFORE AND AFTER GOGGLE TRAINING

Averaged over four goggle training sessions and four participants, shooting percentage on the 25 full-vision shots before the goggle training was 57.2 (SD = 7.1), compared with 62.8 (SD = 11.3) for the 25 full-vision shots after goggle training. The difference was significant as determined using a paired t -test $t(3) = 2.44, p < .05, ES = 0.78$. The direct effects on the extension of the final period during the goggle training seem to be accompanied by an improvement in full-vision shooting performance.

SHOOTING PERCENTAGE IN GAMES: SINGLE-SUBJECT DESIGN

We performed the same analyses as Shambrook and Bull (1996), who used the split-middle technique in which trends in performance before and during intervention are compared and statistically tested for differences. Trend lines are based on the medians of each half of each phase. Original shooting percentages in games were used. As we were interested in comparing performance during baseline with performance during and after the intervention, and to ensure that in all cases there were enough data points, we grouped the percentages during and after the intervention. To guard against inflation of Type-I errors, we expanded the split-middle technique used by Shambrook and Bull to the dual-criteria method developed by Fisher, Kelley, and Lomas (2003), in which data of the (post-)intervention phase were also compared to the mean of the baseline phase.

The results of the participants are discussed in relation to several relevant aspects of performance (see also Shambrook & Bull, 1996, 1996): a) mean performance in each phase; b) change in level of performance, relative to performance trend, from the last day of baseline to the first day of the intervention phase; c) a Binomial Test to assess significance of the difference between performance as projected from the baseline median trend line and post-intervention performance; and d) a Binomial Test to assess significance of the difference between performance as projected from the baseline mean and post-intervention performance. The Binomial Tests determined whether there were sufficient data points in the intervention phase that lie above the performance trend projected from baseline to reject the null hypothesis that there was no change in performance across phases (Fisher et al., 2003; Shambrook & Bull, 1996).

The first set of analyses (figures 2 and 3; Participants 2, 3, 4, and 5 in the EG, and Participants A and B in the CG) is based on game shooting percentages of all field-goal attempts because it is the most complete and used measure of shooting performance. In addition, it ensures sufficient data points, based on sufficient numbers of shots for the single-subject analyses, making them more reliable than analyses based on fewer shots. However, field-goal percentages also include close-range shots such as lay-ups, which can hardly be regarded as representative for aiming at a far target. Therefore, the second set of analyses (figures 4 and 5) was done on the basis of three-point shots (shots from behind the three-point line, 6.25 m from the basket) for those participants who attempted sufficient three-point shots (Participants 2, 3, and 5 in the EG, and Participants A and B in the CG).

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ticipants revealed that there were significant or marginally significant increases in performance when comparing the (post-)intervention data with the projected performance from baseline based on the medians ($p < .001$ for Participants 2 and 4; $p = .05$ for Participant 3). The Binomial tests in which a comparison with the means of the baseline phase was made approached statistical significance for Participants 2 and 3, $p = .054$ and $p = .055$, respectively. For Participant 4 this test was significant, $p < .01$. The above measures point in the direction of improvements in performance after the introduction of the intervention for Participants 2, 3, and 4.

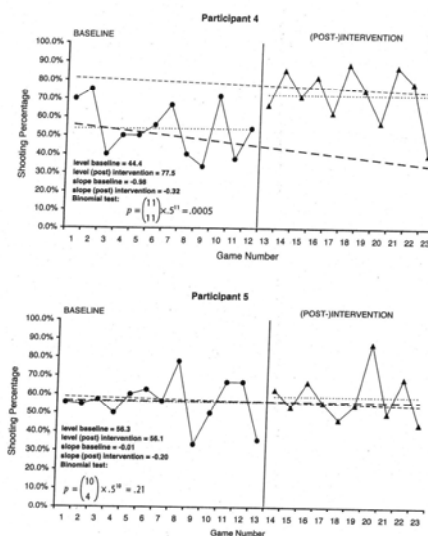


Figure 2. continued

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For Participant 5, mean performance increased with 5.6% from 55.9% during baseline to 59.0% in the (post-)intervention phase. However, level of performance stayed almost the same (see Figure 2). In addition, the Binomial tests were not significant ($p = .21$) indicating that (post-)intervention performance did not diverge from performance as projected from the baseline trends. Together these measures lead to the conclusion that performance of Participant 5 did not improve after the introduction of the intervention.

Participants A and B of the Control Group (Figure 3). Mean performance decreased from 34.8% and 44.8% to 32.7% and 33.4% for Participants A and B, respectively. For Participant A, level of performance dropped from 50.6% to 26.6%. The median

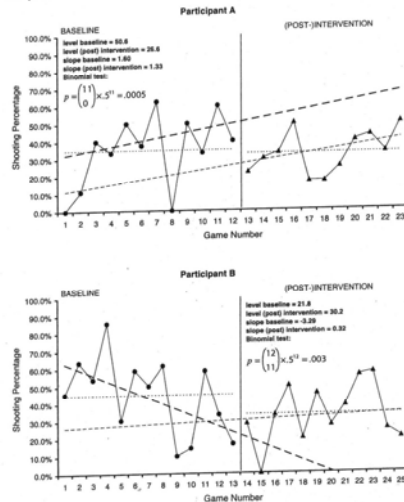


Figure 3. Field goal results for Participants A and B of the CG using the Split-middle analysis. Dotted lines show average performance levels. Striped lines represent the trends in performance (bold = baseline; thin = (post-)intervention). The vertical solid line indicates the transition from baseline to (post-)intervention.

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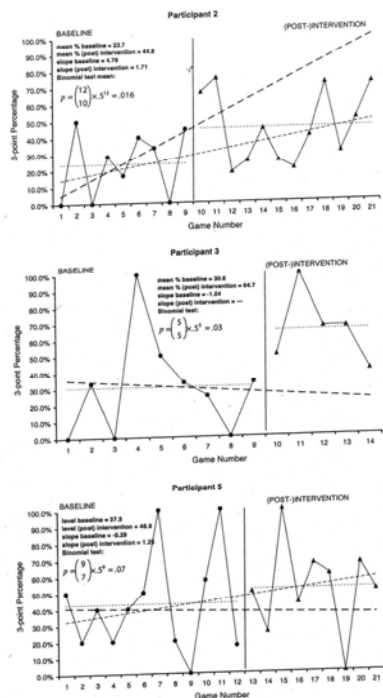


Figure 4. Three-point results for Participants 2, 3, and 5 of the EG using the Split-middle analysis. Dotted lines show average performance levels. Striped lines represent the trends in performance (bold = baseline; thin = (post-)intervention). The vertical solid line indicates the transition from baseline to (post-)intervention.

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Binomial test of Participant A was significant ($p < .001$) indicating that performance was significantly worse after the baseline phase. For Participant B, this analysis was not possible as the slope of the performance trend during baseline was -3.29 leading to a trend line predicting performance lower than 0%. Because the split-middle technique assumes no ceiling or floor effects to limit the slope of the performance trend, projected trend lines may be potentially misleading (cf. Shambrook & Bull, 1996). This is the reason why we used the dual-criteria method introduced by Fisher et al. (2003). For neither of the two participants the Binomial test based on the mean during baseline was significant ($p = .16$ and $.12$, for Participants A and B, respectively), implying that there were no changes in performance. These measures indicate that performance of Participants A and B did not improve across phases.

In conclusion, the analyses revealed that three of the four EG participants showed large and generally significant improvements in field-goal performance across phases. Most, if not all, measurements support the value of the intervention for shooting performance. In contrast, similar improvements could not be revealed for the two participants in the CG.

THREE-POINT SHOTS

Experimental Group (Figure 4). For Participant 2, 3, and 5 mean performance increased from 23.7%, 30.6%, and 42.8% to 44.8%, 64.7%, and 51.2%, respectively, improvements of 21.1%, 34.1%, and 8.4%, respectively. For Participant 2, the slope of the performance trend decreased from 4.76 to 1.71, again compromising the usefulness of the initial slope as a comparative tool (cf. Shambrook & Bull, 1996). The Binomial test based on this trend is significant ($p < .05$), indicating a decrease in performance. However, the other Binomial test that uses the baseline mean is also significant ($p < .05$), indicating an improvement in performance that is in line with the change in mean performance. For Participant 3, a comparison of levels of performance cannot be made as there are only five data points during (post-)intervention. However, the Binomial test can be done. This test, as well as the test based on the mean baseline performance, was significant (both $ps < .05$). Participant 5, who showed no significant increase in field-goal performance (Figure 2), showed a marginally significant improvement of three-point shooting on both Binomial tests ($ps = .07$). There was also an increase in level of performance. Thus, with respect to three-point performance, the above measurements indicate that Participants 2 and 3 as well as Participant 5 improved their performance after baseline.

Participant A and B of the Control Group (Figure 5). There was a slight increase in mean performance from 30.3% to 34.2% for Participant A. Both the change in slope (from 2.78 to 1.11) and the Binomial test based on the medians ($p < .05$) indicate that there was a significant decrease in performance after baseline, but the baseline trend is strongly influenced by the first three games in which the three-point percentage of Participant A was 0. Therefore, once again, the usefulness of this slope as a comparative tool is limited. The Binomial test based on the mean was not significant ($p = .16$) hereby adding

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to the signs that for this participant three-point performance did not improve significantly in the (post-)intervention period. For Participant B, mean performance decreased from 37.5% to 21.3%, while level of performance remained the same. Both Binomial tests were not significant ($p = .22$ and $p = .11$ for the tests based on the medians and the mean, respectively), suggesting that the three-point performance of this participant did not improve across phases.

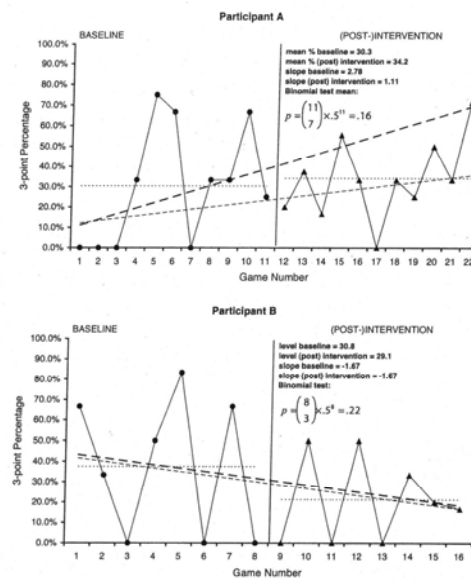


Figure 5. Three-point results for Participants A and B of the CG using the Split-middle analysis. Dotted lines show average performance levels. Striped lines represent the trends in performance (bold = baseline; thin = (post-)intervention). The vertical solid line indicates the transition from baseline to (post-)intervention.

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The results indicate that there were positive performance changes for the participants in the EG after the introduction of the intervention. This effect was also apparent for Participant 5 whose field-goal performance did not improve significantly. These results demonstrate that the EG also improved their performance on long-distance shots. The results for Participants A and B in the CG showed no improvements in three-point performance.

SHOOTING PERCENTAGE IN GAMES: GROUP DESIGN

Table 3: The average game shooting percentages (ratio of the total number of shots attempted and made) of the EG and CG during the three different periods.

Participant	Pre-intervention Period	Intervention Period	Post-intervention Period
EG			
1	37.2	41.5	45.1
2	37.3	42.9	62.9
4	54.2	74.4	74.5
5	55.6	57.9	59.8
Mean	46.1	54.2	60.6
SD	10.2	15.4	12.1
CG			
A	38.0	30.2	41.2
B	44.9	31.0	40.0
C	46.2	47.4	40.0
D	41.0	44.4	47.4
Mean	42.5	38.4	42.2
SD	3.7	8.8	3.6

Table 4: The three-point game shooting percentages (ratio of the total number of shots attempted and made) of the EG during the three different periods. Percentages were not available for Participant 4.

Participant	Pre-intervention Period	Intervention Period	Post-intervention Period
EG			
1	29.8	29.5	47.4
2	33.3	50.0	62.5
4	---	---	---
5	42.6	50.0	51.9
Mean	35.2	46.5	53.9
SD	6.6	6.1	7.8

representing different numbers of shots. The ANOVA showed a significant main effect for the EG across the different phases, $F(2, 6) = 5.30$, $p < .05$, $ES = 1.16$. A similar ANOVA showed no significant main effect across the different phases for the CG, $F(2, 6) = 0.79$, $p > .10$. Thus, whereas the EG significantly increased their shooting percentage from Period 1 to Period 3 the CG did not, greatly reducing the chance that the improvement

We also analyzed the performance data, field goals as well as three-point shots, using a group design. Table 3 presents the shooting percentages for the EG and CG, respectively, during baseline, intervention, and post-intervention. A within-participants ANOVA was used to examine the effect of the different phases of the EG for improvement in shooting percentages during games. Note that we used the percentages presented in Table 3, which are based on the ratio of the total number of shots made (Field Goals Made, or FGM) and the total number of shots attempted (FGA) during each of the periods. These averages may be slightly different from the averages as depicted in single-subject design figures as these are the averages of the data points in the figure, representing

in shooting percentage of the EG was caused by external factors (e.g., seasonal fluctuations in performance for the entire team).

Just as for the total shooting percentages, three-point shooting percentages improved for the three shooters from the EG from Period 1 to Period 2, and from Period 2 to Period 3 (see Table 4). An ANOVA revealed a significant main effect for Period, $F(2, 4) = 10.52$, $p < .05$, $ES = 2.75$, with the three-point percentages improving from 35.2 to 53.9. This finding confirms that the improvements were also reflected in long-distance shots.

Of the CG there were only two participants (A and B) who had attempted sufficient three-point shots. For Participant A, the three-point percentages were 36.4%, 32.4%, and 47.8% for Periods 1, 2, and 3, respectively, and for Participant B 40.0%, 30.0%, and 18.8%. On average, they hit 38.2%, 31.2%, and 33.3% of their three-point shots during Periods 1, 2, and 3, respectively. No systematic improvements over the three periods were visible.

GENERAL DISCUSSION

In this study we investigated the effects of an eight-week visual control training program on basketball jump-shooting performance. During the training, vision was manipulated so that participants could only see the basket during the final instances before ball release. The training consisted of shooting from behind a screen and shooting with special glasses. The dependent variables were duration of the final period, full vision shooting percentages before and after the goggle training, and field goal and three-point percentages in games.

FINAL PERIOD AND LATE-VISION SHOOTING

Participants extended the duration of the final period when shooting with late vision (see Tables 1 and 2). The differences among the two late-vision conditions and the three full-vision conditions, respectively, replicate the direct effect of occlusion on the final period duration found by Oudejans et al. (2002). Expert basketball shooters with a high style are able to change the duration of the final period in order to adapt to a momentary visual constraint. The lack of differences between the screen and goggle conditions suggests that these conditions had a similar direct effect on the final period durations. The difference between the first 25 full-vision shots before the perceptual intervention and the 25 full-vision shots after this intervention implies that there was also a long-term effect on the final period during full-vision shooting. As changes in the final period must be directly related to changes in the movement pattern (cf., Oudejans & Coolen, 2003), these results indicate that a visual intervention can lead to changes in the kinematics of shooting (cf., Harle & Vickers, 2001).

In addition to the extension of the final period duration, four participants improved their shooting with full vision directly after a laboratory training session. This finding is an indication of a direct, and possibly only short-term, effect of the success of the visual

attention training. This suggests that after late-vision training the participants increased their ability to pick up relevant information during the final instance before ball release, a period that was found to be crucial for high-style shooters (Oudejans et al., 2002). The lengthening of the final period could have facilitated this improvement, suggesting perhaps that QE duration in this period did increase a little. We can only speculate about QE since no measures of gaze behavior are reported. Nevertheless, it would be consistent with the findings of Vickers et al. (2000), Williams et al. (2002), and Janelle et al. (2000), showing that longer QE duration is generally a virtue rather than a vice in aiming at a far target. Together with the results of Vickers et al. (2000) and Oudejans et al. (2002), our results with respect to late vision shooting suggest that it is not just the absolute duration of QE that is crucial but the combination of QE duration and QE timing relative to the execution of the aiming movements.

SHOOTING IN GAMES

An important question was whether the training results transferred to competitive games. Participants in the EG improved their game shooting performance (field goals and three-point shots) from baseline to (post-)intervention while the CG showed no improvements. These results highlight the positive effect of our training and are consistent with those of Adolphe et al. (1997) and Harle and Vickers (2001), who also found that visual behavior is trainable, and that this improvement may transfer to game performance.

As to the specific perceptual training that we used, our results seem inconsistent with those of Harle and Vickers (2001). They found positive effects of their perceptual training, but instead of emphasizing late viewing they emphasized early viewing. However, as discussed in the introduction, in basketball shooting visual control may also depend on the style of shooting (Oudejans et al., 2002). While we seemed to have perceptually trained high-style shooters with some success, Harle and Vickers perceptually trained low-style shooters, also with success. Late-vision training fits well with high-style shooting while early training fits well with low-style shooting and the finding that low-style shooters cannot look at the basket from underneath the ball during the final shooting movements (Vickers, 1996).

METHODOLOGICAL CONSIDERATIONS

To be able to value the results it is important to also evaluate the design that was used, as an uncommon combination of single-subject and group design was employed. The continuous assessment in a single-subject design ensures that it is less vulnerable to some of the threats to internal validity (Smith, 1988). Furthermore, the combination of (changes in) mean, level of performance, and the dual-criteria technique (Fisher et al., 2003), led to a more valid evaluation of the effects of the intervention for each individual than simply eye-balling the plots. A relevant question is whether single-subject designs also control for the Hawthorne effect, referring to the possible positive (e.g., motivational) effects of being under investigation. Swain and Jones (1995) make clear that this effect, though potentially a problem, will be minimal if the study is relatively long: "The Hawthorne

effect is most likely to occur after a routine is disturbed, but ... the effect will decline as the subjects become acclimatized to the new routine." (p. 61). As our study was quite long, a possible Hawthorne effect was expected to be minimal during the second part of the intervention and after the intervention.

The internal validity was further guaranteed by including control participants in the single-subject design (see Bryan, 1987) and as a group. Thus, with the combination of single-subject and group design, we were able to guarantee a sufficiently high internal validity in this study. It is obvious that the small samples used in this study limit the generalizability of the results to larger populations. Therefore, it is important to replicate our findings with larger groups in future research. However, it should be noted that the criticism of generalizability holds for statistical generalization and not analytical generalization "in which the investigator is trying to generalize a particular result to some broader theory" (Smith, 1988, p. 9).

THEORETICAL CONSIDERATIONS

Taking an ecological approach it is important to determine whether the changes found are the result of the education of attention (Jacobs & Michaels, 2002), the calibration of action (Withagen & Michaels, 2002) or both. Following the definition of Jacobs and Michaels, it is questionable whether the current improvements are due to changes in variable use. The shooters tested in this study were already good; they did not have to learn how to execute a proper shot. It is unlikely that prior to the experiment they would not have already converged onto using the most useful variable. This is not to say that they would also have already converged onto the use of the most useful values of that variable to set up the action system for shooting. A change in the timing of information detection does not necessarily have to entail the detection of another variable. Values of a variable closer to ball release provide more useful information than earlier values of that same variable as they provide the most up-to-date information to execute a good shot. The idea that attention can also be educated by changing the timing of information pickup implies that education of attention does not necessarily involve a change in variable use (cf. Jacobs & Michaels, 2002; Beek, Jacobs, Daffertshofer, & Huys, 2003). It can still be defined as a convergence onto more useful information, but now either by converging onto more useful variables (Jacobs & Michaels, 2002) or onto more useful values of the same variable induced by an improved timing of information detection.

As actions have to be tuned to the new information after (or during) the education of attention, in our study, next to the change in timing of information pickup, calibration of the shooting action (i.e., the fine-tuning of shooting parameters) to the new information would necessarily also have occurred. Thus, together the education of attention and the process of calibration of action may have been responsible for the changes that were found in this study.

Of course, this interpretation depends on the availability of useful variables. Therefore, it is useful to conclude this section with Figure 6 in order to demonstrate that, in principle, such variables do exist. For accurate shooting it is important to perceive the

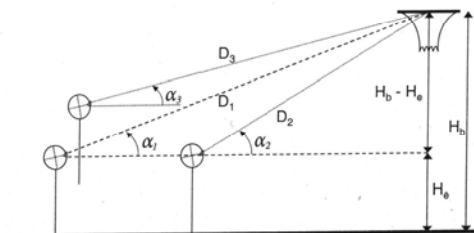


Figure 6. Graphical representation of a shooter shooting from three different positions. D is the distance from the point of observation to the target. α is the angle between the basket, the point of observation, and the horizontal. H_b is the height of the basket. H_e is eye height. See text for further explanations.

distance and height to the rim that the ball has to travel. Without going into possible alternative solutions, the distance between the rim and the point of observation is given by: $D = (H_b - H_e) / \sin(\alpha)$ where H_b is the height of the rim (3.05 m), and H_e is eye height (Figure 6). As height to the rim is given by $H_b - H_e$, both distance and height to the rim are optically specified anywhere on the field (e.g., D_1 , D_2 , and D_3 in Figure 6). When the player is in motion, a continuous updating of this information until ball release provides a possible basis for accurate shooting.

PRACTICAL CONSIDERATIONS

An important issue is how perceptual learning can best be achieved in a practical setting (Williams & Ward, 2003). Williams and Ward discuss two major approaches, the traditional instructional approach, and a more hands-off, or less prescriptive, approach. In the first, the coach or trainer provides explicit instructions and feedback, prescribing precisely what the athlete should do and what information sources to attend to. However, it might be difficult to explicitly point out to which specific variables one should pay attention, especially given "the general ecological assumption that expert performance consists of exploitation of higher order informational variables" (Beek et al., 2003, p. 330).

The second approach assumes that relations between perception and action should be learned implicitly. The way to do this that best fits our intervention, is to constrain the training environment in such a way that athletes are forced to converge onto the use of the most useful (values of) information sources (Beek et al., 2003; Jacobs, Runeson, & Michaels, 2001). By arranging the (time) constraints of a certain task environment, one could increase the chances that perceptual learning follows automatically. In this

way, the coupling between perception and action is preserved, which is considered an important condition for perceptual-motor learning within the ecological approach (Beek et al., 2003; Handford, Davids, Bennett, & Button, 1997; Michaels & Carello, 1981). Future research into specific ways in which this might be achieved in different sport settings is clearly needed.

In conclusion, it is clear that the current study does not provide clear-cut evidence for the ecological interpretation of perceptual improvement, but the results are promising and warrant further research on the effects of visual control training on perceptual-motor performance. They also suggest that visual-control training might be a valuable addition to the usual training practices directed at physical conditioning, learning game tactics, and movement patterns. The training of visual control is rarely done but can improve basketball jump-shooting performance. Our study shows that it can also be easily implemented in practice, as the screen used in this study was a simple and effective tool to train the visual control of basketball players with a high-shooting style.

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AUTHOR NOTE

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